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An Electronic Equalization Technique for Nonlinear Dispersion Compensation in Optical Fiber Link

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Abstract

Gigabit optical fiber communications channels typically exhibit linear and nonlinear distortion as a result of non-ideal transmitter, fiber, receiver, and optical amplifier components. Transmitted data bits begin to spread and overlap as a result of chromatic and polarization-mode dispersion in the fiber, which is exacerbated by the finite spectral width of the modulated optical source. The pulse spreading is pattern dependent and thus can be characterized as inter symbol interference, with associated jitter influenced by the bit rate, component choices, and link length. Any uncompensated link has a maximum data rate and/or maximum transmission length beyond which irresolvable bit errors will be incurred; compensation is required to further increase data rates and/or extend transmission length. Optical correction methods are effective for chromatic dispersion compensation but are difficult to implement for polarization-mode dispersion, which can vary over time and atmospheric conditions. Electronic equalization on the receiver side of the link is an attractive low cost conceptual solution, but is complicated by the nonlinearities introduced by the magnitude-squared response of the optoelectronic receiver. This work describes the development, analysis, and implementation of a technique for purely electronic compensation of both linear and nonlinear distortion mechanisms. A method to approximate the Bit Error Rate (BER) of the equalized system is applied to analysis of the equalization technique using extensive fiber simulations and a numerical equalizer model. The results indicate that the best results can be obtained when the fiber communications channel is tuned to optimize transmission.

Keywords: *Electronic equalization, Nonlinear dispersion, Optical fiber link.*

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1. Introduction

To meet the tremendous demand for transmitted data that is expected in the near future, existing fiber links and related technologies must be pushed beyond their current limitations or completely overhauled. The volume of data transported over fiber networks is fueled by demands for faster transmission of bandwidth-intensive applications such as multi-media broadcasting, remote data networking, online gaming, and high-definition video broadcasts. The optical fiber has traditionally been thought to have unlimited bandwidth. As a result, it has been the transmission media of choice in backbone networks and is rapidly making in-roads into customer premises, enterprise networks, as well as back-plane and storage area networks. The key components of an optical fiber communication link are common to those of many digital communication links. Within the transmitter, an information sequence is used to modulate the intensity of a laser source. For long-haul links (typically greater than 200 km) the optical signal will propagate along multiple spans of fiber with repeated optical amplification to overcome attenuation. In many regional or metro links (40 km to 200 km), the optical signal may propagate along a single span of fiber without additional amplification. In very short reach applications, the optical signal may only propagate a few tens to a few hundred meters through inexpensive, yet pervasive multi-mode fiber. The link can be broken into three key components: the transmitter, the optical channel, and the receiver. While the data rates for optical links exceed those of all other digital communications media, in some respects, they remain among the least sophisticated, using simple on-off keying (OOK) and baseband comparators for symbol-by-symbol data recovery. This trend is likely to reverse itself, as a dramatic change in the nature of optical communications occurred earlier this decade when carriers began to migrate from 2.5 Gb/s to 10 Gb/s transmission rates. As a result of this transition, the performance of fiber optic links in long-haul, metro and enterprise networks became limited by dispersion, or inter symbol interference (ISI), rather than by noise, the transmitted and received symbol patterns as they would appear on an oscilloscope at various stages through the optical fiber. This is largely because group-velocity dispersion (GVD), or so-called chromatic dispersion (CD), in optical fibers increases with the square of the data rate, and becomes a serious impairment at 10 Gb/s. Polarization-mode dispersion (PMD), which arises from manufacturing defects, vibration, or mechanical stresses in the fiber, leading to additional pulse spreading at the receiver, also becomes serious in long-haul transmission at 10 Gb/s and at even shorter reaches for higher data rates. The time-varying nature of PMD gives rise to the additional need for adaptive compensation at the receiver. Modal dispersion, arising from geometrical properties of multi-mode fiber, is also considerably more severe at 10 Gb/s.

2. Dispersion

In optics, dispersion is the phenomenon in which the phase velocity of a wave depends on its frequency. Media having this common property may be termed dispersive media. Sometimes the term chromatic dispersion is used for specificity. Although the term is used in the field of optics to describe light and other electromagnetic waves, dispersion in the same sense can apply to any sort of wave motion such as acoustic dispersion in the case of sound and seismic waves, in gravity waves (ocean waves), and for telecommunication signals propagating along transmission lines (such as coaxial cable) or optical fiber. Non-compensated links have maximum data rates and/or maximum transmission lengths beyond which un-resolvable bit errors will be incurred. Dispersion compensation techniques play an important role in increasing the data content and transmission distance of optical fiber links. Optical, optoelectronic, and purely electronic dispersion compensation techniques have been developed to mitigate the effects of Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD).

Examples of dispersion

The most familiar example of dispersion is probably a rainbow, in which dispersion causes the spatial separation of a white light into components of different wavelengths (different colors). However, dispersion also has an effect in many other circumstances: for example, group velocity dispersion (GVD) causes pulses to spread in optical fibers, degrading signals over long distances; also, a cancellation between group-velocity dispersion and nonlinear effects leads to soliton waves.

Sources of dispersion

- Chromatic dispersion: Glass fibers transmit light of different wavelengths at different speeds. Chromatic dispersion is caused by the combination of material dispersion and waveguide dispersion.
- Material dispersion: Glass fibers exhibit the property of different wavelengths of light exhibiting different indices of refraction and, therefore, travel at different speeds.
- Waveguide dispersion: In single-mode fibers, a portion of the light travels outside the core of the fiber, which has another index of refraction, therefore, broadening the pulse.
- Polarization mode dispersion: Light pulses are composed of two distinct polarization modes, which normally travel at the same speed, traveling at different speeds due to random imperfections and asymmetries, causing random dispersion of wavelengths.
- Intermodal dispersion: Each mode of light travels a different path, some shorter and some longer distances. As a result, the modes will not be received at the same time and the signal will be distorted.

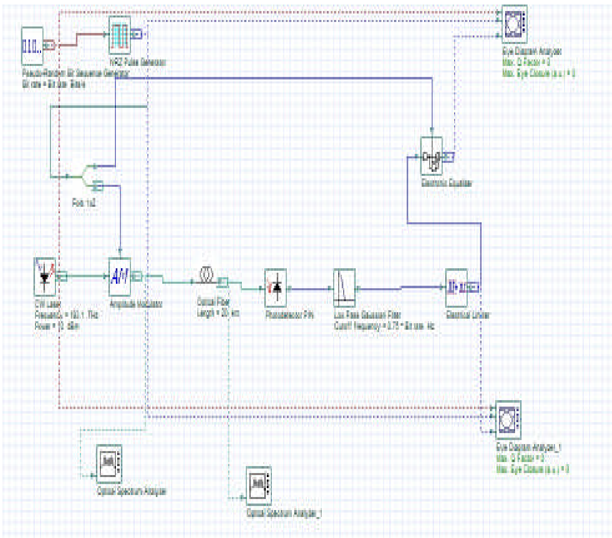

Fig. 1: NRZ Pulse Generator

3. Design and Simulation

Fig. 1 shows the NRZ pulse generator is used as input which passes through the optical. Electronic equalizer is used to show the equalized form of output. This output is seen in the Eye diagram analyser which is put before and after the equalizer to compare the outputs. Fig. 2 shows the RZ pulse generator is used as the input. Rest all connections are same as the NRZ pulse generator diagram. The wavelength of the CW Laser is taken as 193.1 THz

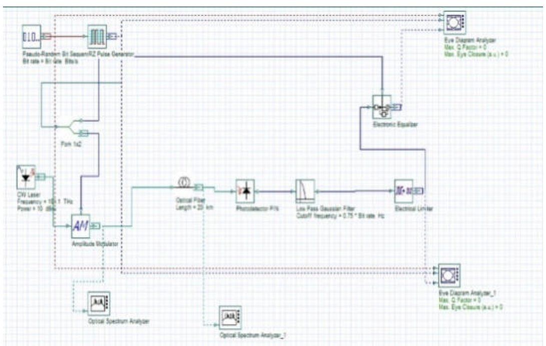

Fig. 2: RZ Pulse Generator

in both the cases. Optical spectrum is also used to get the output of the input light before and after passing through the optical fiber.

4. Result and Discussion

In the simulation, different types of non linearity's are analysed. Different types of visual parameters are used to obtain the nonlinear analysis. The main analysis tools taken into account are Q factor, BER, Spectrum, Oscilloscope Visualizes etc. Eye diagram is the methodology used to evaluate the performance of the system. The important parameters of eye diagram are Quality factor and Bit error rate.

A. Eye diagram analysis by using NRZ pulse generator

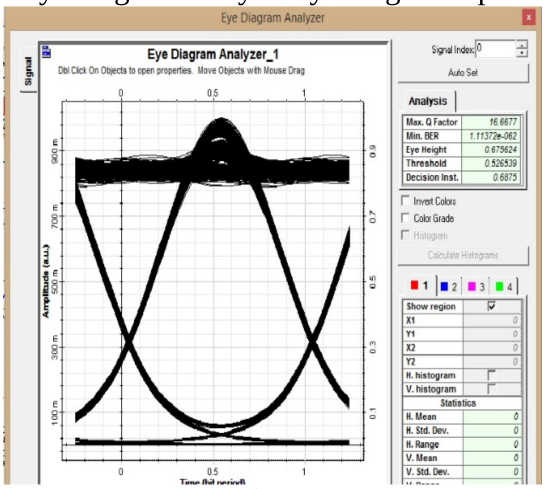

Fig. 3: Before equalizer

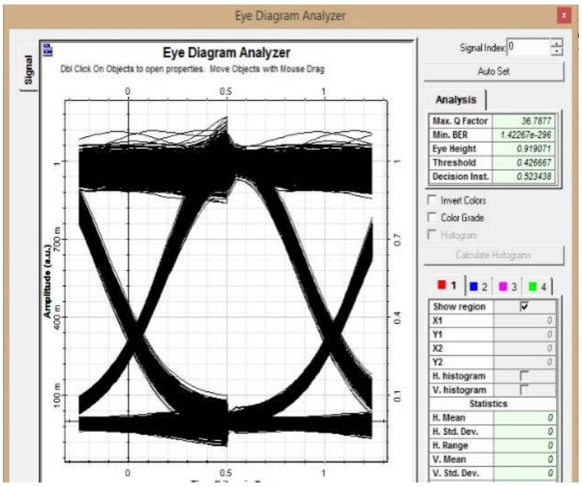

Fig. 4: After equalizer

B. Using RZ pulse generator

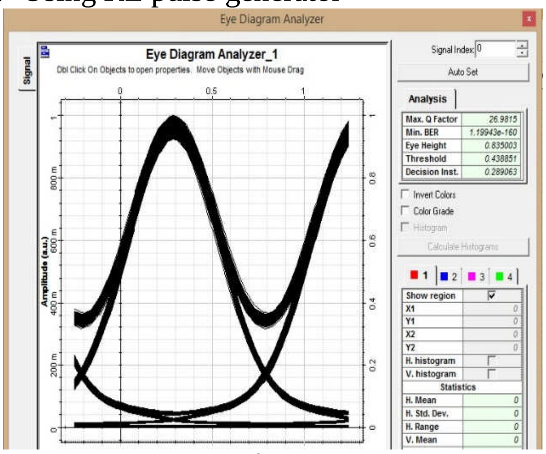

Fig. 5: Before equalizer

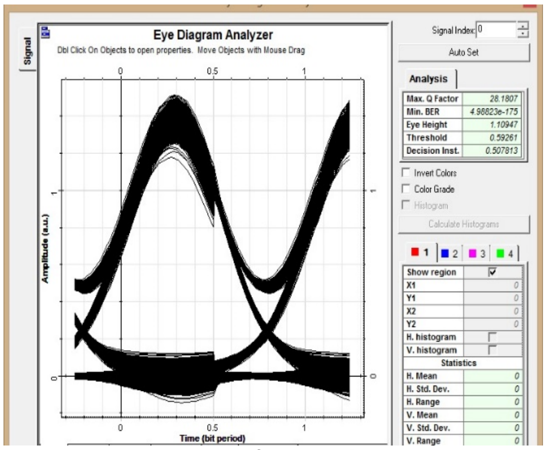

Fig. 6: Before equalizer

C. Optical spectrum

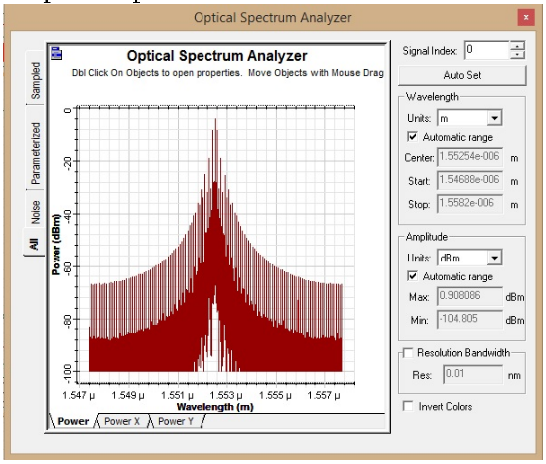

Fig. 7: Initial optical spectrum

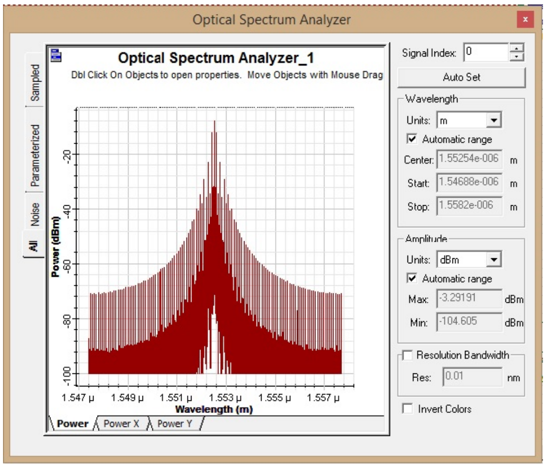

Fig. 8: Optical spectrum after passing through optical fiber

5. Conclusion

Hence it is concluded that the equalizer is very useful for the dispersion compensation. It can be for both NRZ and PZ pulse generator.

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